ANTARCTIC TEMPERATURE STUDIES UTILIZING HRIR DATA FROM NIMBUS I

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ABSTRACT

Eighty nine orbits of Nimbus I High Resolution Infrared (HRIR) data (August 28 - September 22, 1964) were analyzed and compared to data from the reporting stations on the continent of Antarctica. Out of 281 station reports containing all types of weather typical of the Antarctic, it was found that the surface temperature of stations reporting cloudless conditions correlated best with the HRIR temperatures interpreted from the HRIR film.

This paper includes a discussion of the methods used and the difficulties encountered in extracting usable data from the low contrast HRIR pictures over a homogeneous ice and snow covered area.

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Aus. = Australia

BIMED = See [2]

C = Degrees Centigrade

CDC = Control Data Corporation

HRIR = High Resolution Infrared Radiometer

K = Degrees Kelvin

mb = millibar

NASA = National Aeronautics and Space Administration

So. = South

TIROS = Television and Infrared Observational Satellites

U.K. = United Kingdom

U.S.A. = United States of America

U.S.S.R. = Union of Soviet Socialist Replublics

VOM = Volt Ohm Meter

1. INTRODUCTION

The Antarctic Continent is a vast wasteland, about one and a third times larger than the United States, over which the most vicious weather in the world occurs. For man to live in this hostile climate, mere survival becomes a full time job. Scientific endeavors aimed to discover more about the world's deepfreeze require a large support force, many supplies, and much planning to carry out even the most simple of operations. Of course, weather is of prime importance for the successful completion of any scientific undertaking and is the concern of all who have to work in it. With only 12 stations regularly reporting surface weather over such a vast area, it is easy to realize the awesome task of preparing a forecast with any degree of confidence.

It was the purpose of this thesis study to develop methods by which weather forecasters may profitably use satellite information over the continent. The Television and Infrared Observational Satellites (TIROS) have proven to be invaluable in other parts of the world where conventional data are scarce or lacking, but over the huge ice and snow covered glaciers, plateaus, and mountains of the Antarctic, the TV daylight pictures show little difference between snow and clouds. During the long Antarctic winter the TIROS camera system would be of no use even if clouds were distinguishable. With the advent of the High Resolution Infrared Radiometer (HRIR) camera system by which a satellite can take infrared pictures of the cloud systems, a new analysis and forecast tool was born. Although the infrared pictures of the clouds over the snow covered terrain did not live up to the authors' expectations, it can be seen from this paper that the information derived is of importance.

2. HISTORY AND BACKGROUND

A. The Antarctic

The United States Navy has responsibility for providing the meteorological logistic support required by the United States military forces and civilians in the Antarctic. This requires weather forecasting services to insure maximum operating efficiency. It is evident that nowhere in the world does weather dictate the extent of human behavior and aspirations as it does in the Antarctic. Unfortunately, this is an isolated region of which little is known, and consequently, there exists a lack of current and historical meteorological data for all operating regions. This poses quite a formidable forecast problem.

The Antarctic continent comprises an area of approximately 5,500,000 square miles (Figure 1), over 90% of which is covered with perennial ice and snow. The continent may be considered a plateau whose height ranges from sea level to 2,000 meters very close to the coast, continuing to 4,000 meters near the centrum of the land mass [9]. It is flanked by two large indentations, nearly diametrically opposed, which are the Weddell and Ross Seas. The Ross Sea is covered to one half of its area with ice almost all the time. This ice shelf is afloat and ranges from 300 to nearly 3,000 feet thick at its location closest to the pole. The Filchner Ice Shelf in the Weddell Sea is nearly as large but does not cover as large an area of the sea. The ice thickness ranges from 100 to 800 feet.

There were, in 1964, approximately 32 surface observation stations in the Antarctic, of which only 12 regularly reported to the Antarctic Analysis Center in Melbourne, Australia. Upper air data reporting stations are even more limited, (Table I). Contrast this with 292 first order stations over 3,500,000 square miles of the United States and the problem of the Antarctic forecaster becomes apparent.

The polar night over the Antarctic continent causes a prolonged cooling of the snow surface which makes this an immense permanent source of very cold air. Because of the intense outgoing surface radiation, the Antarctic air masses display the characteristic polar inversion usually found within the first 1000 feet above the surface. Moreover, these air masses are stable aloft and undergo slight heating as they katabatically drain toward lower levels [1] [3] [9] .

In the past it has been considered that no special methods of analysis were required in the Antarctic. However, besides the inherent difficulties associated with sparse observational networks, the high average elevation places in doubt the validity of a continuous sea-level analysis. Moreover, it is usually believed that cyclones which reach the Antarctic continent are in their final or occluded stages, but these decaying systems lack the sharp frontal features of mature mid-latitude disturbances and are therefore difficult to discern. Additional problems are found when these systems fill and disappear at the surface but persist for long periods as vigorous cold lows aloft.

This paper discusses a system using HRIR satellite data to aid the analysis and forecaster in some of the problems and frustrations encountered in Antarctic meteorological operations. Many of the same problems occur in other areas, such as Greenland, Siberia, and the Himalayas and the techniques discussed herein may be applied to such areas.

B. Meteorological Satellites

(1). TIROS and Nimbus Systems. With the advent of the TIROS series on April 1, 1960, a new era in weather analysis and prognosis was born. The data received have been of two types, daylight television pictures taken by narrow to wide angle camera systems and infra-red radiation information. It was hoped that the daylight pictures would be equally useful all over the world; however, in snow and ice covered regions, clouds were frequently indistinguishable from the snow and ice. With the use of radiation sensors on some TIROS (e.g., TIROS II, III, IV, and VIII) and Nimbus satellites, it was hoped that problems of this type would be solved since the temperature of the cloud tops and surface temperature would normally be different. The radiation data in the early systems were low to medium resolution but with the advent of Nimbus, high resolution [12].

(2). HRIR Radiometery [4]. The High Resolution Infrared Radiometer on the Nimbus operated in the 3.5 to 4.1 micron window region. This spectral range corresponds to a very clean atmospheric window and the observed radiation intensities should provide an excellent indication of the surface and/or cloud temperatures and temperatures gradients. [8].

Operationally, the infrared radiation impinging on the satellite is reflected from a scan mirror and refocused at the detector (lead selinide photoconductive cell). The resulting alternating current signal is amplified by a linear logarithmic amplifier, then rectified, resulting in direct current output. This output and the radiometer sync pulse time signals are transmitted to receiving stations on earth. The radiometer output received at the ground station is demultiplexed and recorded first on magnetic tape, then on strips of photographic film with fine resolution and a continuous gray scale. The film is then gridded by special grid point equipment (GRIPE) which generates the conventional latitude and longitude grids and the orbital and spacecraft attitude. The gridding assumes no altitude changes of the satellite and this results in location error. Table II gives altitude and other pertinent data on Nimbus I.

Regarding temperature, preflight calibration runs were made with black body target temperatures between 190 K and 340 K in discrete steps and the radiometer output voltage was recorded at each step. After the unit was integrated in the spacecraft another calibration was performed with the same temperature range and the associated frequencies matched against the temperatures. Close examination of both sets of calibration data revealed no significant changes in over eight months of handling and installation in the spacecraft. The temperature read-out at the receiving stations is a function of a selenide cell temperature whose variations are not completely known.

During the relatively short life time of Nimbus I (28 August - 22 September 1964) there were 121 picture-taking passes over the Antarctic continent. On each pass there were about four stations within the picture area. Some passes had more and some less but almost every picture contained the pole itself. The conventional surface and upper-air observations taken at the pole station are among the best taken in the Antarctic. With the very high saturation of reported data at the pole, this station has turned out to be the most consistent source of verification figures.

3. OBJECTIVES

Given the setting, outlined in Sections I and II, it became the objective of this study to provide a means of properly identifying surface and/or cloud top temperature during clear and cloudy conditions over the Antarctic continent by the use of High Resolution Infrared Radiation data which are available from the Nimbus I satellite. If such a method could be developed it would be of utmost importance in the preparation of weather maps and short range planning so necessary for operations in the Antarctic.

Up until now several authors have stated that it was impossible to utilize the poor-contrast HRIR pictures over the Antarctic continent itself and have devoted their efforts to the water area adjacent to the continent [10], [11]. Thus, the first task became one of technically overcoming the formidable problem of discerning small variations in the shades of gray on Nimbus photographs of the Antarctic area.

4. DATA

A preliminary study of the feasibility of such an investigation was made utilizing information from the "Nimbus I High Resolution Data Catalogue and Users' Manual" volume I (4). The contact prints of available HRIR photofacsimile film strips contained in the manual (appendix C of (4)) were studied and the stations contained in each picture were spotted. The gray intensities on the pictures were compared to the variations of the gray scale. A four-day trial was conducted to see if any relation of HRIR temperature to surface temperature or reported weather was evident to the naked eye. It appeared as if the colder temperatures were associated with clear weather. At the conclusion of this preliminary trial the positive film transparencies were ordered from N.A.S.A. Space Science Data Center [7]. It was then learned that the pictures in the Users' Catalogue were enhanced so that the gray gradation range was increased (i.e., whites would be whiter and the dark areas would be darker). This enhancement was also available on film and would have made interpretation much easier and far more distinctive, but, the enhancement process did not include the gray scale to the same degree that it did the pictures. Thus the unenhanced positive filmstrips were ordered and received from N.A.S.A. The contact prints in the Users' Catalogue were still used to spot the location of stations and aid in verifying interpretations from the film.

The National Weather Records Center of Asheville, North Carolina, furnished micro-film copies of the charts drawn by the International Antarctic Analysis Center in Melbourne, Australia, for the period 28 August to 22 September 1964. It turned out that the micro-film copies of the analysis were of such poor resolution that the individual station models were unreadable. Also included in the micro-film copies were the time cross sections of each station which included both surface and upper air data for each of the twelve stations. These data proved to be invaluable in the subsequent analysis. Surface, 700mb, 500mb, and 300mb data for each station were extracted from the cross-sections and tabulated.

Meanwhile, copies of the original charts were ordered from the International Antarctic Analysis Center. Although they arrived too late[1]

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[1] The map copies were requested to be mailed by air from Australia but due to a mix-up in the Consulate General's office in Melbourne, the maps were sent by surface mail. The extra two-months delay would have created insurmountable difficulties had the micro film cross sections not been available.

to contribute significantly in the project development, they have proved their worth in sensing the synoptic scale features of the Antarctic circulation patterns and in the verification.

5. EVALUATION OF DATA

A. General Description

The subsatellite tracks of Nimbus I are shown in Figure 5. The tracks are asymmetric relative to the pole. The satellite pictures themselves have a latitude-longitude grid superimposed for reference. This was found to be of great help although there was evident error at times (Figure 4). This is due to the fact that the satellite was not in a perfectly circular orbit and the CDC 924 computer, which placed the grid on the picture, was not programmed to compensate for the ever-apparent changing geographical location of the apogee and perigee. The maximum computer error, discovered with the aid of detailed Antarctic maps [6] , was observed to be around 130 nautical miles. Thus, where a visible land mark was identified, the station location was spotted geographically rather than by grid. The places where land marks were identifiable were generally the places where there was a marked difference in the photographic intensity indicating a large change in surface temperature over a relatively short distance. This occurred frequently along the coast where the cold land and the "warm" ice meet. Otherwise, where there was no other evidence of error, the computer grid was used exclusively. For interior stations, when the geography was not identifiable, the temperature gradient was usually weak. Overall, it is believed all stations were spotted within one degree latitude accuracy.

Illustrations of the aforementioned problems are shown in Figures 2, 3, and 4. When the coastline of the Antarctic continent is well delineated, as in Figure 4, it is quite easy to spot the station location accurately. The computed station positions are indicated by ⊙ and the geographical position by ⊡ . When compared to the computed grid it can be seen that there are errors of 80 and 130 miles in locating stations 022 and 001, respectively. There are no geographical fixes near station 125, therefore the computed position is used exclusively. Station 125 is on the edge of a very cold region (light gray) but if its position was spotted in the direction of the corrections applied to 001 and 022, it can be seen that quite a different radiation intensity would result. It may introduce more error to make such a correction, because the computed location errors change over the area of the picture.

As can be noted from Figures 2 and 3, picture contrast between the clouds and the underlying snow and ice on the Antarctic leaves much to be desired.

Notice the general overall darker area penetrating inland toward the pole in Figure 2. This is the Ross Ice Shelf (area a). To the north of this area is pack ice (area b). The overall contrast of these underlying water areas is quite different from the underlying land areas (area c).

From the mottled effect of the gray, there appears to be broken to overcast clouds over areas a and b. The distinctive shading along 160E toward the pole is due to the Queen Alexander Range and Queen Maud Range. These mountains have peaks ranging from 10,000 ft. to 15,000 ft. The off-shore cloud features are due to synoptic scale weather systems and are outside the area of interest here. On Figure 3, the American Highlands (area between 60 and 80E) may be viewed. This shows up as a relatively dark area, features of which are probably associated with the off-shore cloud system.

Due to the fact that there is such a little difference in the gray scale of the picture over the Antarctic continent a special method was needed to obtain an accurate reading of the infrared value. It was then decided, with consideration of picture size and instrument sensitivity, that an area of approximately 60 miles in diameter should be used to verify the HRIR measurement around each station. This should take into account station location errors and give an over-all view of the area surrounding the station in question. This also allowed some leeway in the time lag of reporting data due to the fact that the satellite was passing over some station every ninety-eight minutes but the station took observations at a maximum of only once in three hours. In some cases the verifying upper-air report was as much as 12 hours off from the satellite passage, while six hours was the maximum time differential allowed between conventional surface and satellite observations.

B. Experiments on Film Interpretation

The method of limiting the "read area" to only 60 miles in diameter led to the development of an optical-mechanical technique for reading the pictures accurately.

(1). Visual. At first the naked eye was used. The intensity of the gray at each station was compared to the gray scale. Each of the two authors scanned a pass on the film-strip and recorded the radiation temperatures independently. Findings were compared and factors which went into their individual estimates discussed. Differences as high as 10K were found. Then a value, mutually acceptable to both, was recorded. After five data-days of this procedure, it was decided that the method was too subjective, since, when confronted with pictures which had been evaluated earlier, significantly different temperatures were interpreted.

(2). Selenium light meter. The second method made use of a light meter. A selenium light cell was obtained and the sensitive portion masked off so that only the light from a circle 60 miles in diameter was allowed to strike the cell. The low sensitivity inherit in a selenium cell was reinforced when most of it was masked off. Once again it was found that the readings obtained were not consistent when the same photograph was repeatedly scanned. This was due to the very small meter deflections and the operators' inability to discern any change. A one thousand-watt light box was obtained for the purpose of driving more light through the small hole, but the accuracy was far from what was desired.

(3). Cadmium-sulfide cell. Finally, it was decided to design a system which would very accurately measure a small amount of light from a source of small areal dimensions. A cadmium-sulfide cell was procured with a sensitivity window masked to two millimeters in diameter; the appropriate diameter for one degree latitude on the HRIR film. The light cell was used in conjunction with a Heathkit Volt-Ohm-meter (VOM)[2]. As the light intensity was increased, for a given voltage across the cell, the resistance decreased logarithmically. This was read on the VOM. By applying different voltages to the cell, any sensitivity range desired could be obtained. The cell was so sensitive that a reading varied significantly over different parts of the "constant" light source. This problem was overcome by using a piece of opal glass which diffused the light so that it was uniform over an area of three inches by four inches. This was the area used in the following description.

C. Method for Interpreting Pictures

The HRIR photograph was laid on top of the one thousand-watt light box and the cadmium-sulfide cell was placed over the location of the stations, one by one (Figure 6). The relative value of light intensity

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[2] A Knightkit VOM was compared,with the same results.

at each station was recorded and compared with the accompanying gray scale. The values of the gray scale were recorded using the same light source and techniques as used on the picture. The picture values were interpolated to the correct radiation temperature associated with the gray scale values. This temperature was then recorded on the data sheet for later comparison to observed atmospheric temperatures obtained at that station. Figure 7 shows the authors reading this HRIR film and recording the data for later analysis.

D. Method for Interpreting Gray Scales

The use of the gray scales was not without difficulty. During the electronic transmission of the satellite pictures from the satellite to the ground receiving station one side of any given step on the gray scale wedge was printed darker than the other. As a consequence, one side of a relatively light step on the scale (x on Figure 8) was darker than the other side of a relatively darker step on the scale (y on Figure 8).

Several methods were tried in an attempt to evaluate the gray scales in a manner such that the reading would be consistent.

(1). Mean value. The first method established a mean intensity for each step of the gray scale wedge by averaging the lightest and darkest intensities on each step. However, it was found that many times the mean value of the lightest (coldest (210K)) step had a lower (that is warmer) reading than the next warmer step (225K).

(2). Area matching. Each HRIR film strip was superimposed over the gray scale wedge and the picture intensity at each station was matched to the gray scale at the same relative position of each step. This effectively had the same results as the first method.

(3). Zonal. Each gray scale step was divided into five zones (Figure 8) and all intensity readings for a given film strip were made in one zone only. Again, results were unsatisfactory.

(4). Zonal step. Finally, a system was devised by which a consistent method of reading the temperature could be maintained. Using the gray scale, as divided into five zones, the lightest reading was accepted as being the coldest temperature recorded. The next coldest temperature was accepted as the next step up and the next zone in, and so forth. In Figure 8, a locates the lightest reading. According to the scheme, the progressively warmer temperatures were measured in the order a, b, c, d, e. If necessary to go to warmer temperatures than 250K the value read on the VOM at e was found in the 255K line, then f was located one zone to the darker side. This procedure was repeated each time the dark side of the scale is reached.

E. Difficulties

(1). Gray scale. In some cases a temperature on the picture was recorded which was colder than the coldest zone of the lightest gray scale step. In such cases the radiation temperature was extrapolated.

Another big problem was in the actual interpolation. In some instances,within the first two or three steps in the gray scale (the coldest being first), only small changes occured when going from one step to the next. Then the third or fourth step, as the case may be, would have a very large change (be much darker) relative to the steps above. Thus, interpolation in the cold steps was very difficult due to the small spread, while interpolation between the last light step and the first dark step was very easy because of the large spread. This fact gave the authors a sense of uneasiness in that a more uniform gradation was expected and needed for accurate temperature estimates. However, on many of the passes there was a very smooth gradation of the gray scale which was read and interpolated.

(2). Station location. As mentioned in another part of this paper, the exact location of the station is very difficult to determine. This becomes critical when aiming toward a correlation between the HRIR temperature and a meteorological or temperature parameter in the earth-atmosphere system. This is especially important for the stations along the coast. A movement of the light sensor of less than one-half millimeter will, in some cases, give a change of HRIR temperature of 15K to 20K. This is due to the very marked temperature change from the underlying land to the underlying water. The dark gray or black line implying warmer temperatures can be noted at certain points along the coastline in almost every picture (note the center of Figure 4 near station 001). If the light sensor is allowed to read a little of this area adjacent to the station, it will indicate much warmer temperatures than otherwise. Only by comparison with the reported temperature at the cloudless station in question will the sensor operator know exactly where to spot the sensor, which of course introduces intolerable subjectiveness into evaluations along the coastlines, as well as inhibiting analysis and forecast potential of the system.

6. EVALUATION OF RESULTS

A. Cloudless Conditions

Objective readings[3] were taken at all stations over which the satellite passed for the period of 1 September through 22 September 1964. First, the stations which reported cloudless conditions were studied to evaluate the relationship of observed surface temperature[4] to the radiation temperature interpreded from the HRIR. The temperatures for 52 stations reporting cloudless conditions were correlated. Figure 9 shows the results. This result was considered fair with a simple correlation coefficient of 0.70 and a standard error of estimate of 8.9 K. It was then decided that, because of the above large error, a "second reading" should be taken which had as its purpose to obtain the smallest

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[3] An objective reading is one taken without knowledge of cloud or surface conditions.

[4] Surface temperature refers to the temperature at the instrument shelter level. According to Hatherton [5] the gradient between the six-foot level and the snow surface varies between one and three degrees Kelvin, dependent on wind conditions.

actual deviation between HRIR temperature and reported surface temperature within one degree latitude of the station's spotted position. This reading was taken with full knowledge of surface temperature. In one sense this approach had the purpose of more accurately locating the station in question. As expected, the correlation as seen in Figure 10 was much better, with a simple correlation coefficient of 0.95. The standard error of estimate dropped to 4 K. This is still not within the 1K-2K accuracy the authors desired for the proposed analysis technique. These results clearly illustrate the critical nature of accurately locating any geographical point.

B. Cloudy Conditions

In addition to the correlations computed for the cloudless conditions, scatter diagrams were plotted for a number of other parameters related to HRIR temperature under cloudy conditions.

Figure 11 shows the relation of HRIR and surface temperature with 0.1 to 0.5 low cloud cover (bases less than 600 feet). It was believed that the temperatures of the tops of low clouds might be related to the surface temperature, and hence, allow a good correlation in this restricted sample. As can be seen from the scatter diagram the result was poor.

Figure 12 is the same as the last except for 0.6 to 1.0 cloud coverage. Unexpectedly, the relation is at best the same or a little better than the scattered cloud case.

It might be expected that the temperature at the tops of low clouds would be related to inversion temperatures, so the HRIR values were plotted against the inversion top temperatures (Figure 13) with 0.9 to 1.0 low cloud coverage. The results showed only that the inversion temperature for the stations sampled is homogeneous within 10 K.

Figure 14 shows the HRIR temperature versus the inversion-top temperature with 0.8 to 1.0 middle clouds. This gave a unusable wide scatter of points.

Correlations were not computed in the casesof Figures 11, 12, 13, and 14.

C. Wind Speed and Direction

The katabatic winds were thought to have an effect on the observed low level temperature structure so a multiple correlation was set up between surface wind speed, the katabatic wind direction, the HRIR temperature and surface temperature for cloudless conditions.

The surface topographic contours in the area surrounding the station were studied and the direction of steepest gradient was assumed to be the direction from which the katabatic wind blows. For correlation purposes a 120° sector straddling the predominate katabatic wind direction was assumed positive. The adjacent 60° sectors were assumed 0; all other angles were negative.

It was found that katabatic winds blew approximately 75% of the time. When wind speed and direction were included in the correlation for cloudless conditions, the correlation improved slightly from 0.70 to 0.72.

D. Regression Program and Comparative Results

The BIMED III program [2], which is a linear multiple-regression program, and the BIMED VIII program, which is a polynomial-regression program, were used in correlating the more promising data. The programs were run on the U. S. Naval Postgraduate School's CDC 1604 computer utilizing Fortran 63 programs.

Figure 15 shows a direct comparison of the resulting regression lines. The straight solid line is the regression curve produced from the objectively read data in which the observer had no knowledge of surface temperature.

The curvilinear solid line was produced by the BIMED VIII program from the same data. Notice that it matches the aforementioned curve very well through the center part of the curve. This was the area where the data were concentrated. Less than 10% of the data were found at surface temperatures between -50C and -60C.

It was decided to use the linear program (BIMED III) because of the additional statistical parameters which it also computed.

The dashed line is the regression line found when the data from the "second reading" were used.

7. CONCLUSIONS

The information derived and the studies made with this new meteorological medium leaves much to be desired in the present state of the art. As time progresses, successive generations of satellites will make giant strides to eliminate many or all of the problems which were encountered in this study. With Nimbus II hopefully achieving a circular orbit, the problem of station location from the computer grid should be solved. The biggest problem to be solved is the gradation of the gray scale. When such scales are accurately interpretable, it is believed that a useable nephanalysis and temperature analysis could be produced for Antarctic type areas by the methods described here. At any rate, it is hoped that the interpretation technique developed here will benefit future research in this field.

8. RECOMMENDATIONS

The research described heretofore is suggestive of additional facts worthy of investigation. These are outlined below.

A. Numerical Applications

The extreme cold temperatures of the Antarctic are associated with very low humidities to such an extent that the radiosondes motorboat immediately upon release. Without the important moisture parameter for analysis, cloud bases and tops cannot be accurately determined.

In an overcast condition there is no way, except possibly by radar returns, to tell where the cloud tops are located. In the future when all the technical problems of Nimbus are eliminated, the HRIR detector may become the link to fill in this missing information. With an HRIR temperature accuracy of one or two degrees Kelvin, cloud top height of the highest deck of clouds could readily be determined by the intersection of the sounding temperature and the HRIR temperature, the latter with, perhaps, some adjustment.

Expanding upon this idea for the entire Antarctic continent, or any large area with a limited number of temperature soundings, this information could be introduced to a high speed digital computer in the form of a three dimensional array to simulate the three dimensional atmosphere. A first guess would utilize climatology of pressure, temperature, and height data from the surface to 300mb with the lower boundary set by terrain level. By introducing any available current soundings and cloud information into the model array, a first estimate of the current temperature for each geographic or grid point of each level may be derived by some horizontal analysis technique. This would produce a three dimensional depiction of the thermal height structure in the atmosphere from the surface to the top of the model.

By an adoption of the methods described in this paper, an automated picture scanner could be devised and the HRIR temperature specified for each grid point with the use of an analog computer. The HRIR value could be read directly into the digital computer and stored in a two dimensional comparison grid. Then by direct comparison of the HRIR and analyzed temperatures for each grid point at a discrete number of horizontal levels, proceeding systematically from the top to the bottom of the atmosphere, a level could be found where the HRIR temperature and the estimated temperatures were equal. This may be the point of the top of the highest cloud for that grid point, or it may match the surface temperature indicating cloudless conditions prevail. After all grid points were compared in this manner and the height and temperature of the cloud tops stored in another computer grid, a mapping of cloud top heights and temperatures could be drawn.

Since inversions are found most of the time during the Antarctic winter, it is highly probable that the HRIR temperature could be matched to at least two different levels. Since an inversion is close to the surface, the upper temperature would be recorded as the cloud top level. If, however, the HRIR temperature is close (within one or two degrees) of the surface temperature, points horizontally adjacent would be compared. If, at the adjacent points, cloudless conditions prevail, then the point in question would also be assigned no cloud. If the point in question is adjacent to a reporting station it would be made to agree with that station's cloud cover, or cloud climatology may be utilized to help solve such problems.

From the statistical studies encountered by the authors and the correlations found and presented in this paper, it can be said that the satellite HRIR data are not yet to the point of acceptability that is required for a program of the type just outlined.

B. Observed Phenomena

While studying the HRIR film, it was noticed that a dark (warm) spot appeared quite frequently and always in the same location (about 75 S-163 E). Out of 32 picture-taking orbits over this area, this event occurred 27 times.

A very limited investigation by the authors revealed nothing to account for this phenomena. Further study of this unique occurrence is recommended.

9. ACKNOWLEDGMENT

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BIBLIOGRAPHY

1. Ball, F. K. Winds on the Ice Slopes of Antarctica, Antarctic Meteorology (Proceedings of a Symposium held in Australia in 1959). New York: Pergamon Press. 1959.

2. Biomedical Computer Program, Health Sciences Computing Facility, Department of Preventive Medicine and Public Health, School of Medicine, University of California, Los Angeles. January, 1964.

3. Biter, Cleon J. and Stinson, J. Robert. Deviations between the Surface Wind and the Geostrophic Wind on the Antarctic Continent. Presentation at the American Meteorological Society Conference on Modern Methods of Weather Forecasting and Analysis in Chicago, Illinois on March 24, 1966.

4. Goddard Space Flight Center. Nimbus I High Resolution Data Catalogue and Users' Manual, Volume I. National Aeronautics and Space Administration, January 1965.

5. Hatherton, T. New Zealand IGY Antarctic Expeditions. Scott Base and Hallet Station. Bulletin 140. New Zealand Department of Scientific and Industrial Research. 1961.

6. National Geographic Society. Antarctic Atlas, plate 65. The National Geographic Magazine, February, 1963.

7. Nimbus Data, Code 650, N.A.S.A. Space Science Data Center, Goddard Space Flight Center, Greenbelt, Maryland, 20771.

8. Reap, R. M. and Fujita, T. Death Valley Temperature Analysis Utilizing Nimbus I Infrared Data and Ground-Based Measurements. Satellite and Mesometeorology Research Project, University of Chicago, August, 1965.

9. U. S. Navy Weather Research Facility. Notes on Antarctic Weather Analysis and Forecasting. NWRF 16-1260-038, Norfolk, Virginia, December, 1960.

10. Widger, W. K. and Smith, R. B. Meteorological Interpretation of Nimbus High Resolution Infrared (HRIR) Data. Final Report. Contract NO. NAS5-9554. Aracon Geophysics Co. August, 1965.

11. Widger, W. K. and Smith, R. B. Preliminary Results From a Meteorological Evaluation of Nimbus I HRIR Data. Preliminary Scientific Report. Contract No. NAS5-9554. Aracon Geophysics Co. May, 1965.

12. Widger, W. K. and Staff, Meteorological Interpretation of Nimbus High Resolution Infrared (HRIR) Data. NASA Contractor Report. Contract No. NAS5-9554. Prepared by Allied Research Associates, Inc., Concord, Massachusetts, January 1966.

TABLE 1

Antarctic Stations With Reporting Interval

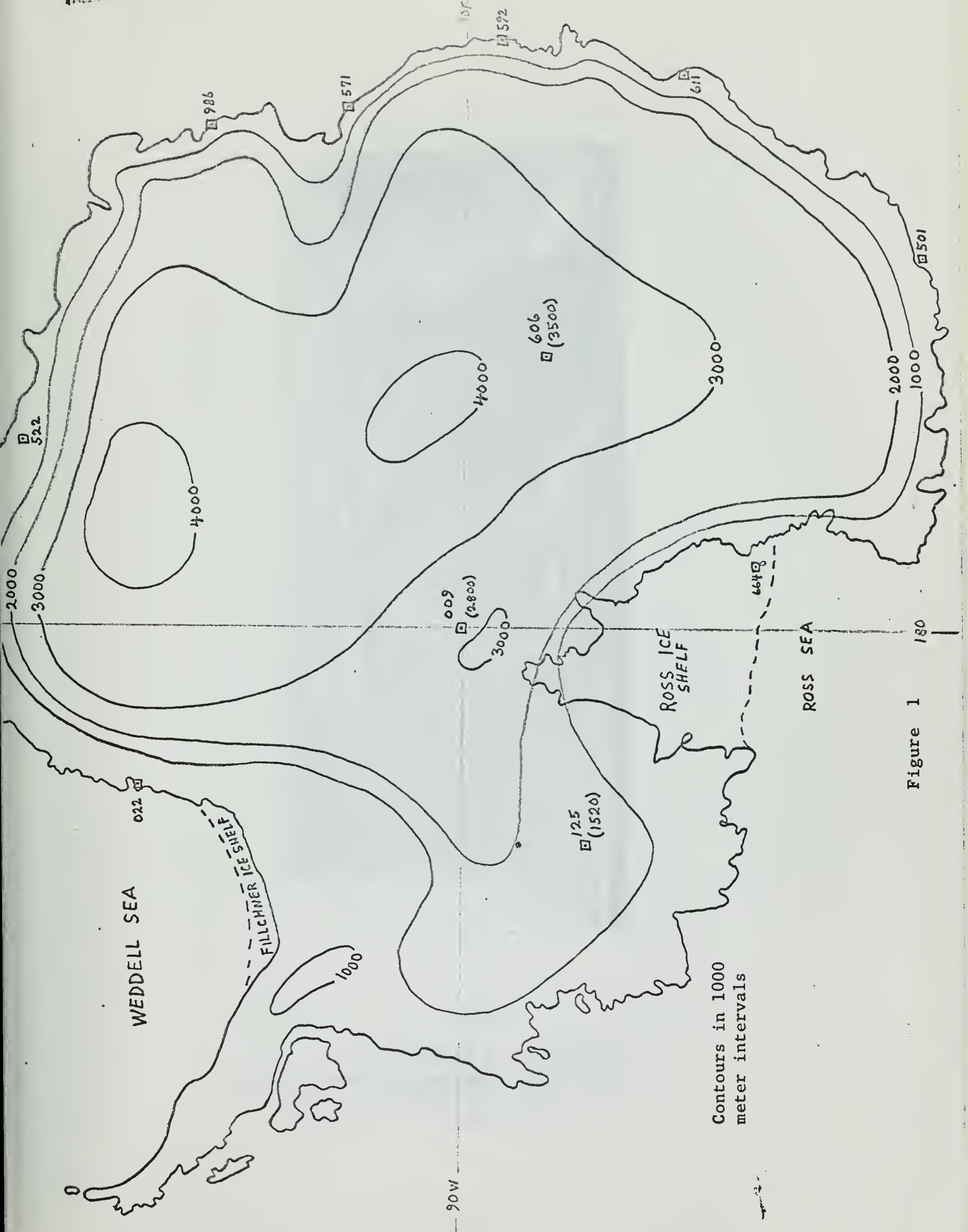
Station Number	Station Name	Reporting Interval (hours) Surface	Upper air
001	Sanae (South Africa)	3	24
009	Amundson-Scott (U.S.A.)	3	24
022	Hallet Bay (U.K.)	6	24
125	Byrd (U.S.A.)	3	24
502	Dumont d'Urville (France)	3	none
522	Roi Baudouin (Belgium)	3	24
571	Davis (Aus)	3	12*
592	Mirney (U.S.S.R.)	6	12
606	Vostok (U.S.S.R.)	6	none
611	Wilkes (Aus.-U.S.A.)	3	12
664	McMurdo (U.S.A.)	3	24
986	Mawson (Aus)	3	12*

*Alternate radiosonde and pilot balloon

TABLE 2

Nimbus I Satellite Facts

Perigee height	423.2 kilometers
Apogee height	937.7 kilometers
Anomalistic period	98.31 minutes
Inclination	98.66 degrees
Orbits per day	14.6
Lifetime of HRIR	26 days (28 Aug-22 Sept 1964)
HRIR scan spots (apogee)	7.3 kilometers
HRIR scan spots (perigee)	3.3 kilometers
Selenide cell temperature variation	-76.5 to -69.8 degrees centigrade



Contours in 1000 meter intervals

Figure 1

Figure 2

HRIR Photo of Ross Sea area
(orbit 059, 1 September 1964)

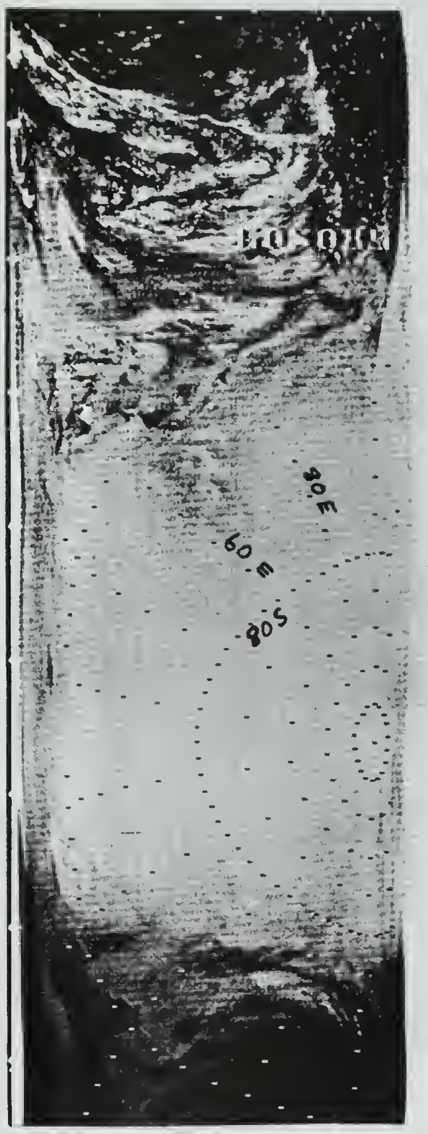
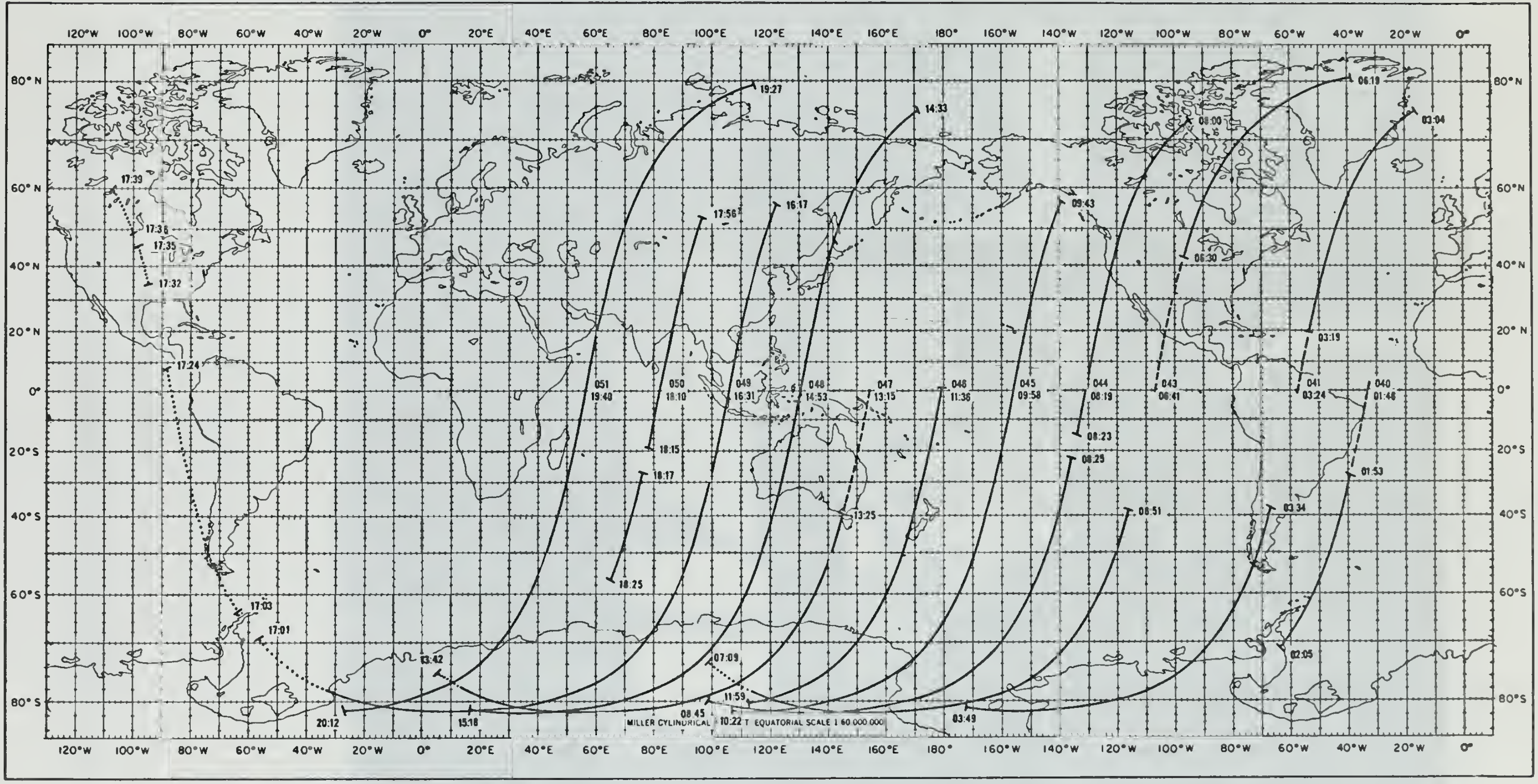


Figure 3

HRIR Photo of American Highlands area
(orbit 049, 31 August 1964)

Figure 4

HRIR Photo of Weddell Sea area illustrating
station location problem
(orbit 023, 29 August 1964)



AUGUST 31, 1964

FIGURE 4. NIMBUS I ORBITAL TRACKS

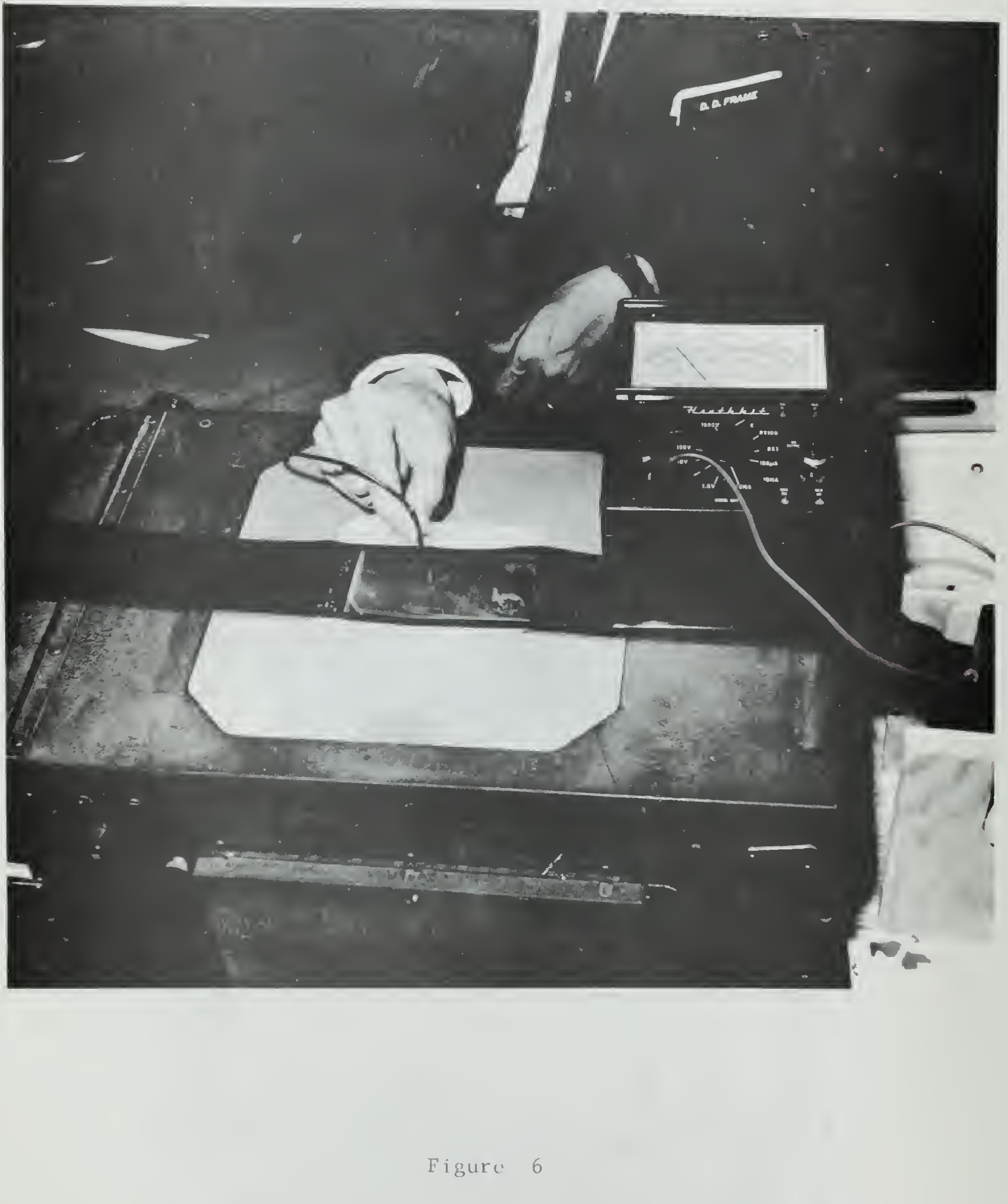


Figure 6

Operation of reading an HRIR temperature

Figure 7

The authors reading the HRIR film and recording data

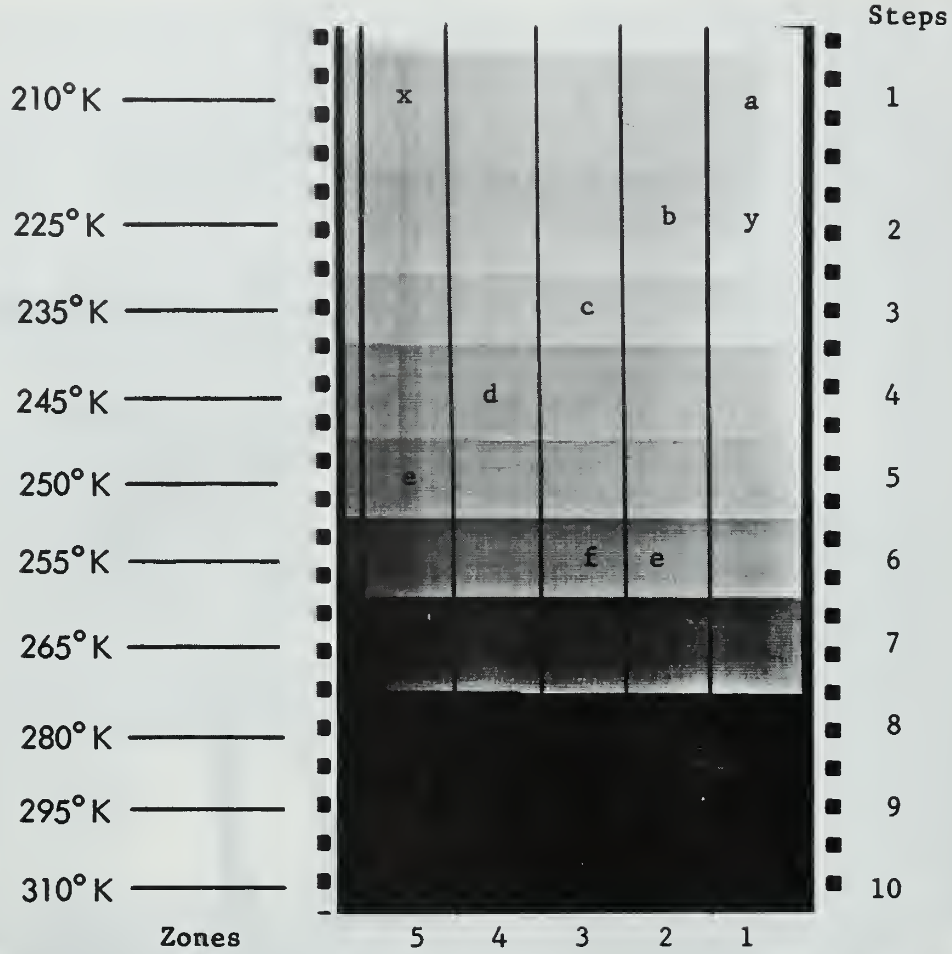


Figure 8

Ten step gray scale wedge

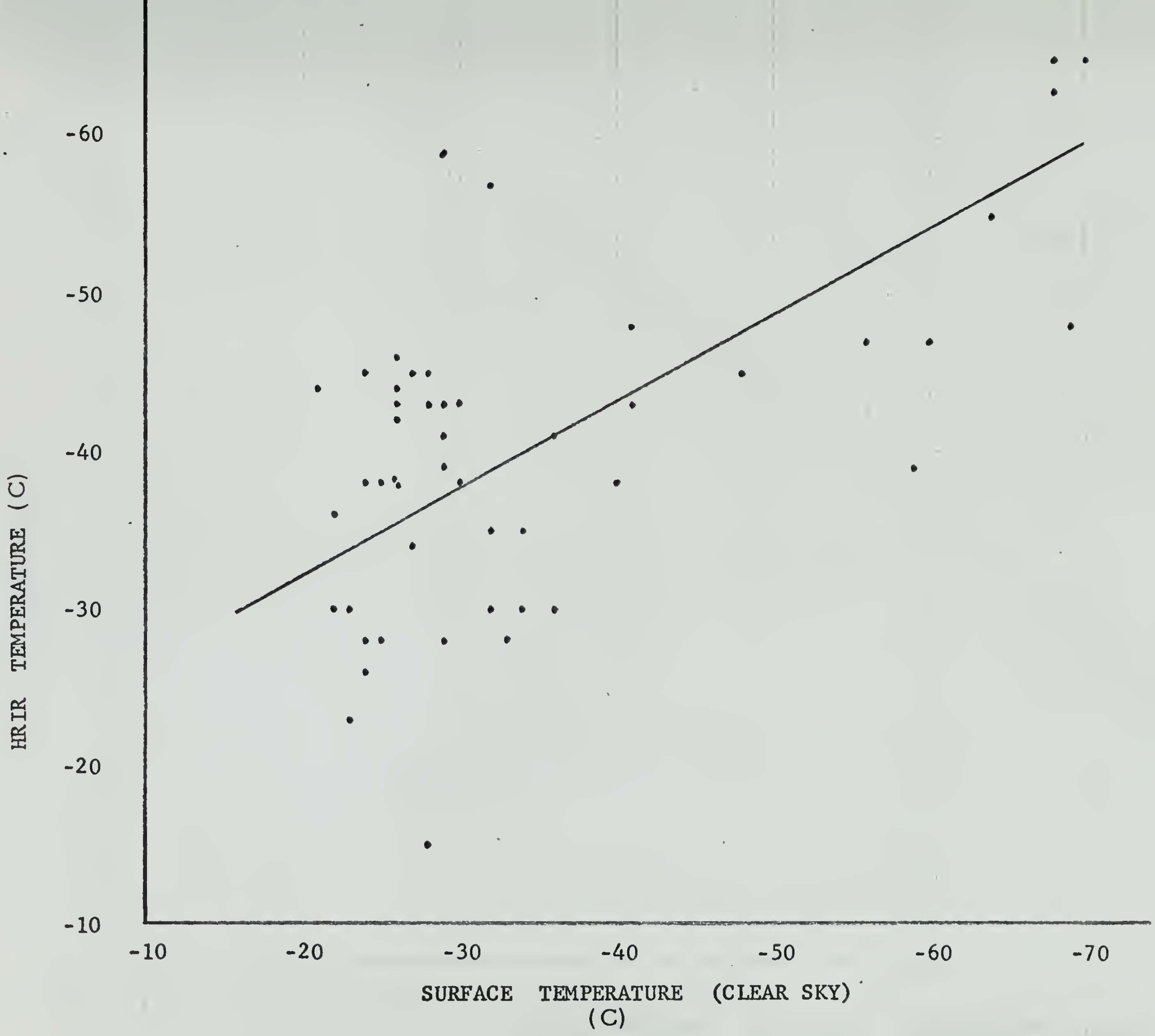

-60
-50
-40
-30
-20
-10
HRIR TEMPERATURE (C)
-10
-20
-30
-40
-50
-60
-70
SURFACE TEMPERATURE (CLEAR SKY)
(C)

Figure 9

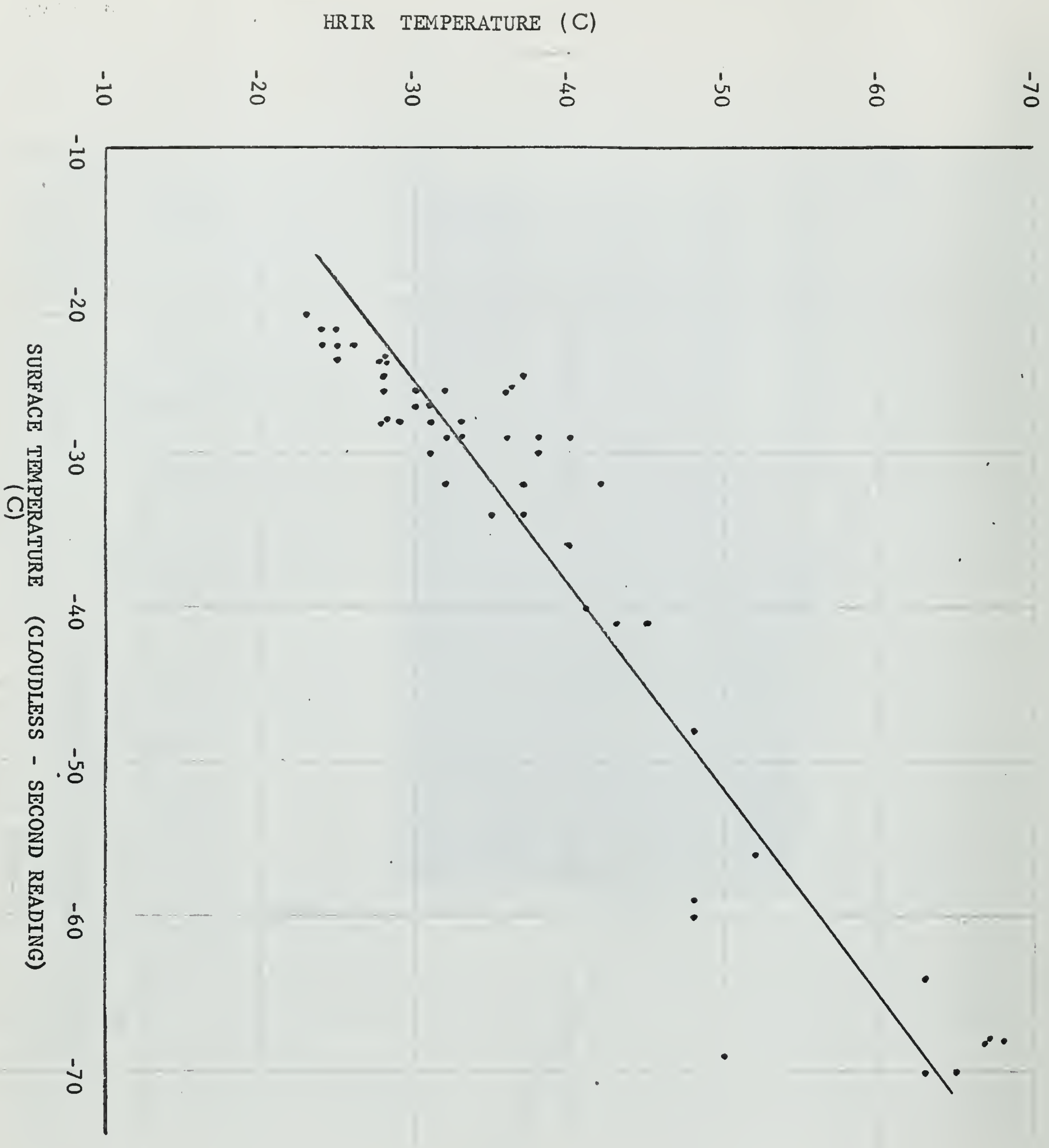

HRIR TEMPERATURE (C)
-10
-20
-30
-40
-50
-60
-70
-10
-20
-30
-40
-50
-60
-70
SURFACE TEMPERATURE (CLOUDLESS - SECOND READING)
(C)

Figure 10

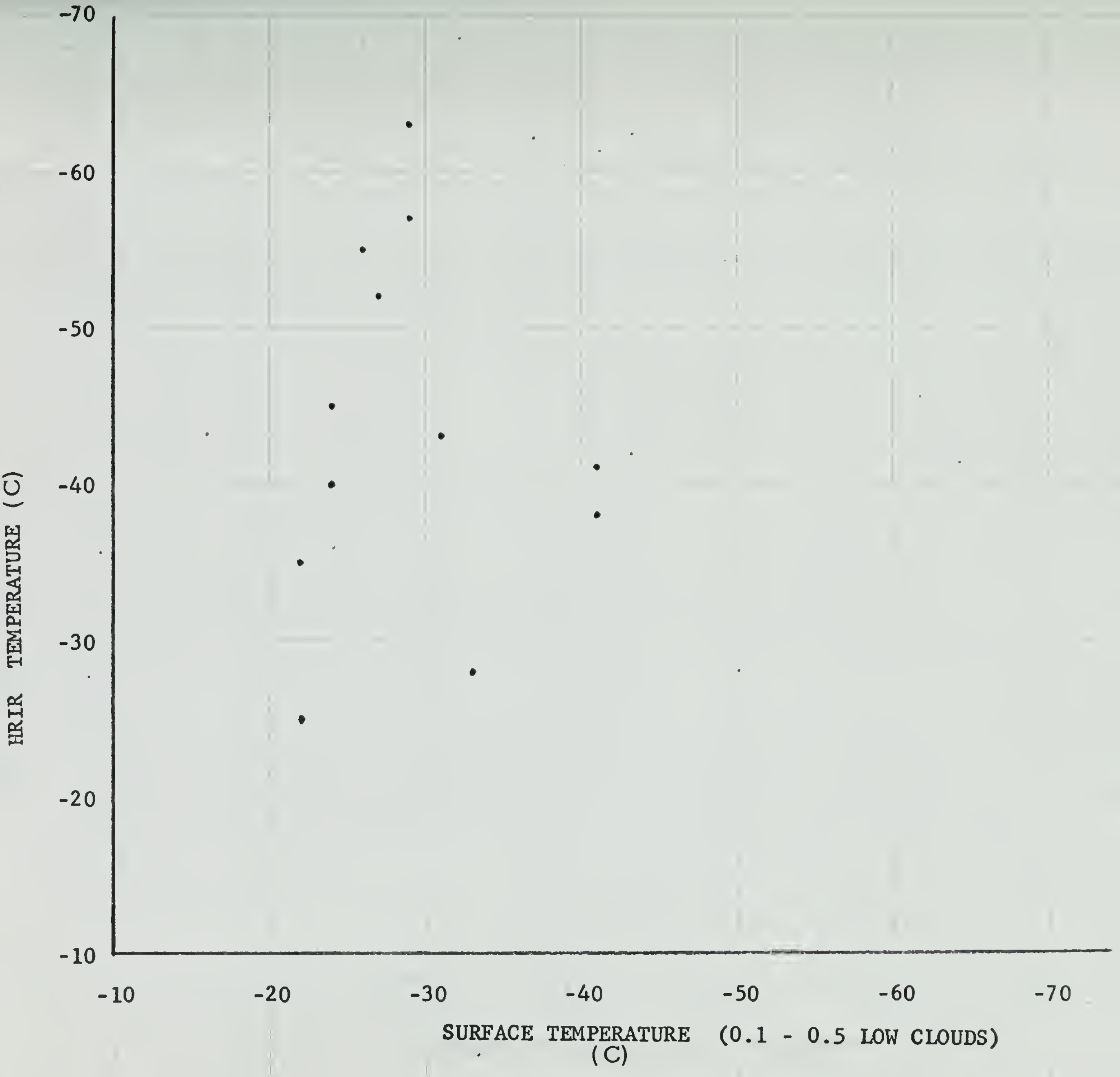

-70
-60
-50
-40
-30
-20
-10
HRIR TEMPERATURE (C)
-10
-20
-30
-40
-50
-60
-70
SURFACE TEMPERATURE (0.1 - 0.5 LOW CLOUDS)
(C)

Figure 11

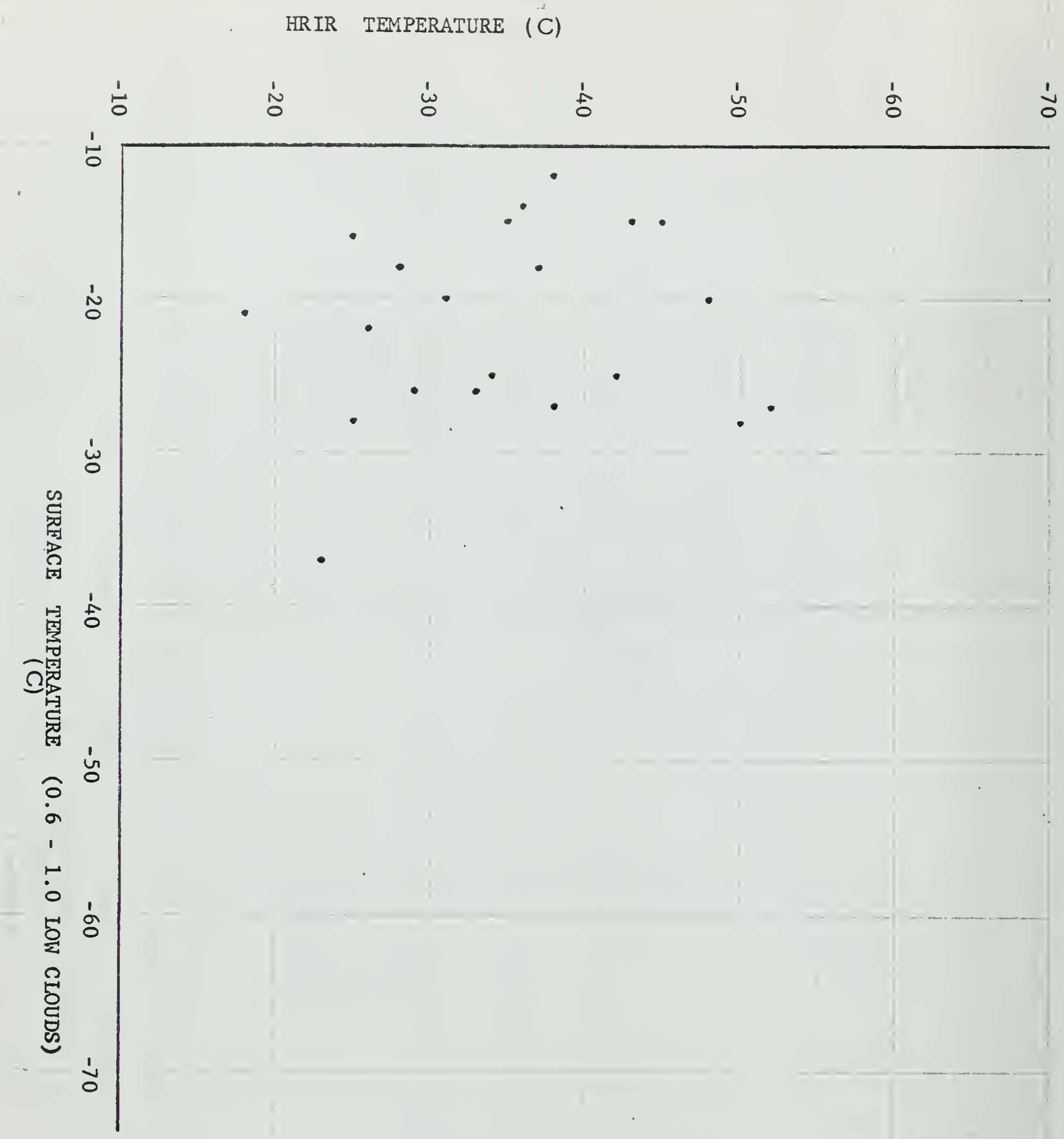

HRIR TEMPERATURE (C)
-10
-20
-30
-40
-50
-60
-70
SURFACE TEMPERATURE (C) (0.6 - 1.0 LOW CLOUDS)
-10
-20
-30
-40
-50
-60
-70

Figure 12

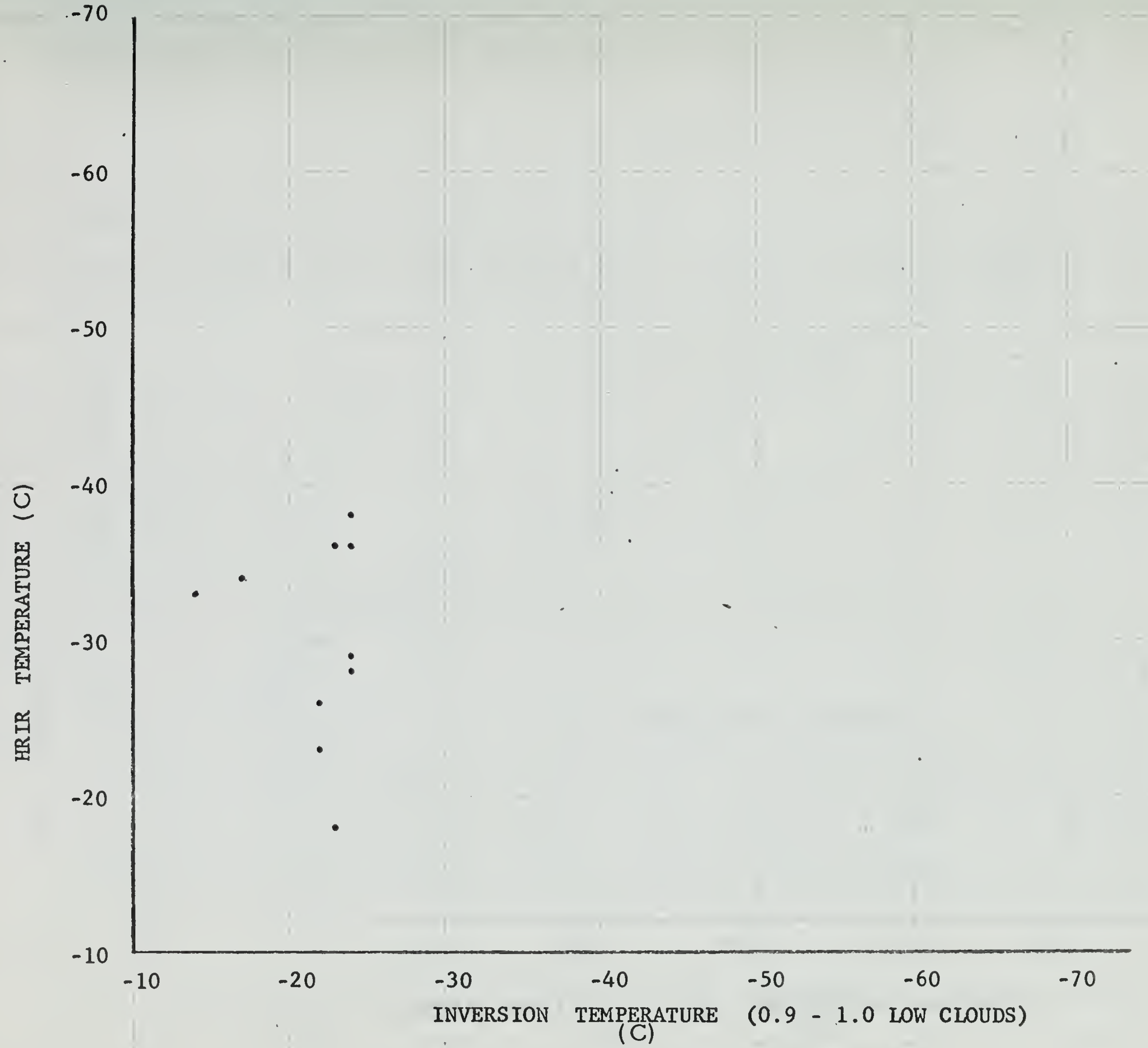

-70
-60
-50
-40
-30
-20
-10
HRIR TEMPERATURE (C)
-10
-20
-30
-40
-50
-60
-70
INVERSION TEMPERATURE (0.9 - 1.0 LOW CLOUDS)
(C)

Figure 13

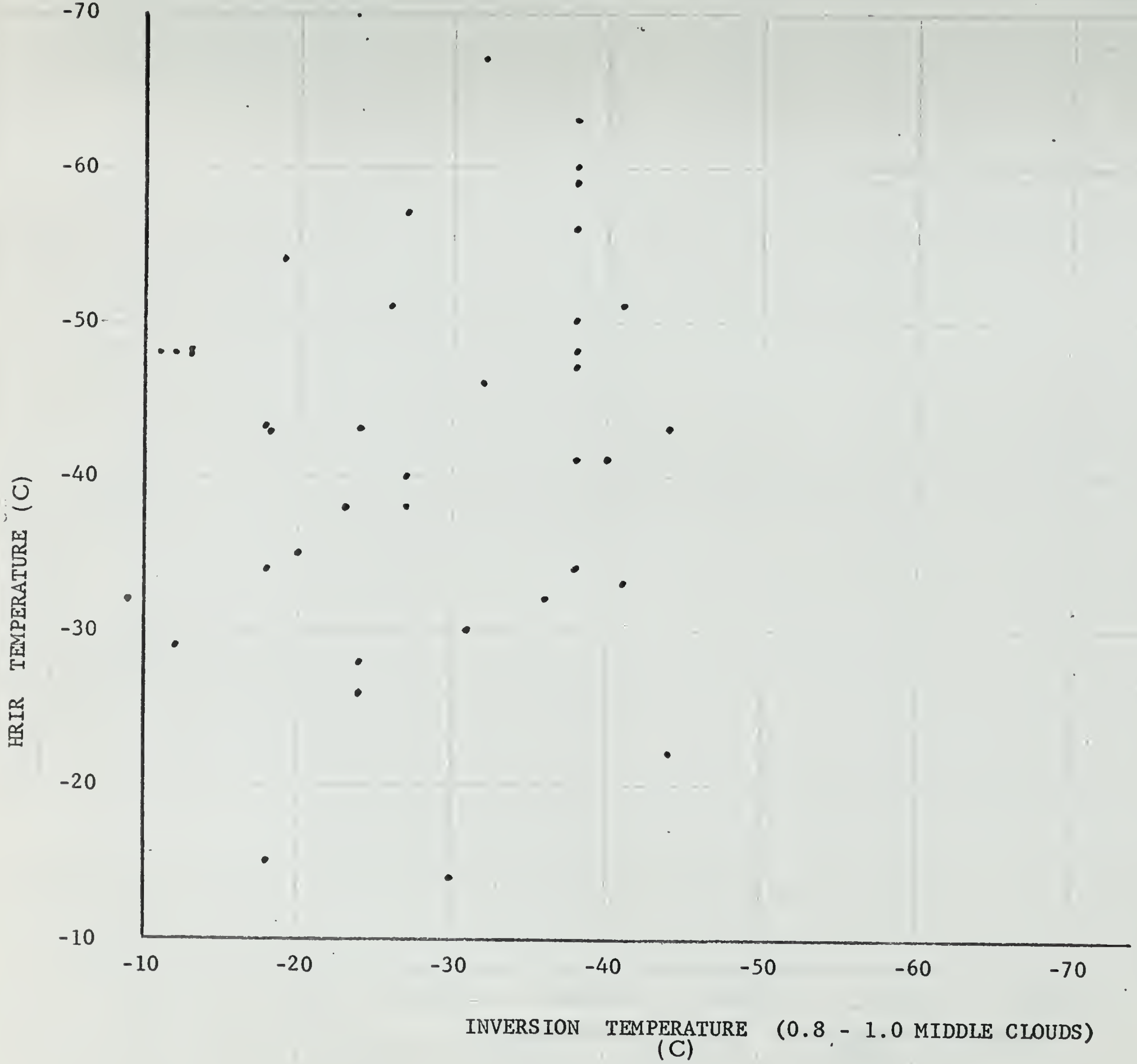
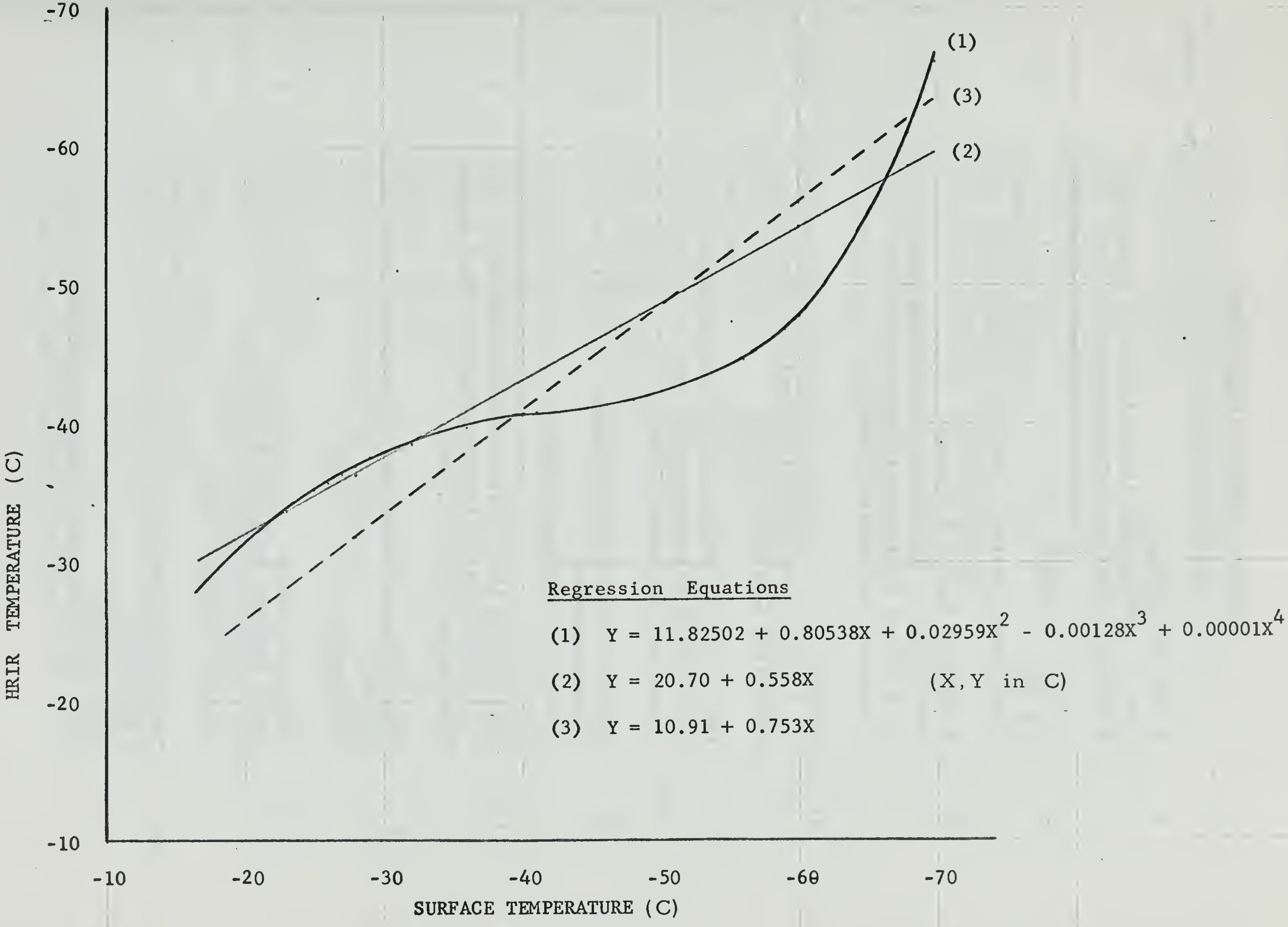

HRIR TEMPERATURE (C)
-70
-60
-50
-40
-30
-20
-10
-10
-20
-30
-40
-50
-60
-70
INVERSION TEMPERATURE (0.8 - 1.0 MIDDLE CLOUDS)
(C)

Figure 14



Regression Equations

(1) $Y = 11.82502 + 0.80538X + 0.02959X^2 - 0.00128X^3 + 0.00001X^4$

(2) $Y = 20.70 + 0.558X$ (X, Y in C)

(3) $Y = 10.91 + 0.753X$

Figure 15

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Eighty nine orbits of Nimbus I High Resolution Infrared (HRIR) data (August 28 - September 22, 1964) were analyzed and compared to data from the reporting stations on the continent of Antarctica. Out of 281 station reports containing all types of weather typical of the Antarctic, it was found that the surface temperature of stations reporting cloudless conditions correlated best with the HRIR temperatures interpreted from the HRIR film.

This paper includes a discussion of the methods used and the difficulties encountered in extracting usable data from the low contrast HRIR pictures over a homogeneous ice and snow covered area.

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